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LAWRENCE LIVERMORE NATIONAL LABORATORY

New Technologies for Monitoring UCG

R. J. Mellors, X. Yang, S. Hunter, J. Wagoner, W. Foxall, D. Camp, S. J. Friedmann

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Disclaimer

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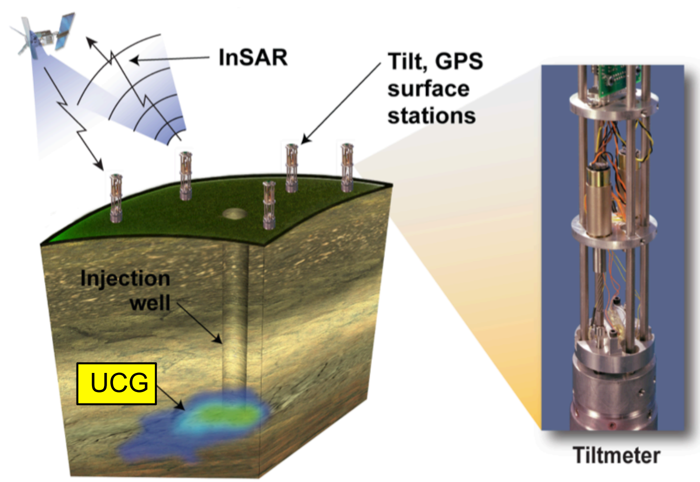
Lawrence Livermore National Laboratory (LLNL), USA

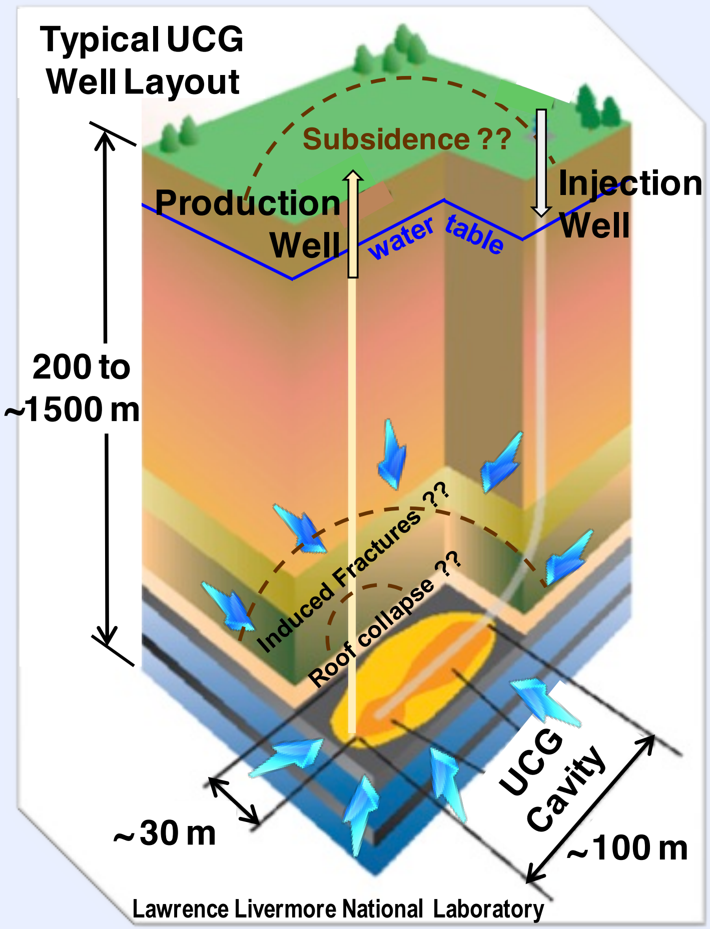


28th Annual International Pittsburgh Coal Conference. Sept. 12-15, 2011

UCG – Underground Coal Gasification

Alternative to surface gasification

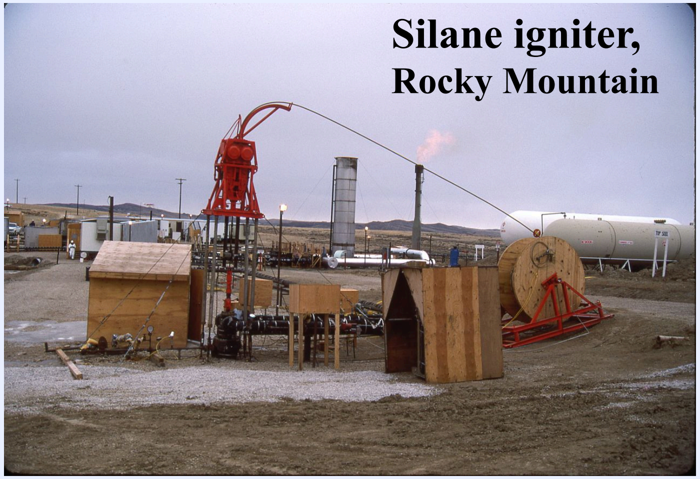
- UCG uses the coal seam as the gasification reactor to concert coal to syngas underground
- Coal +O2+H2O => H2, CO, CH4, CO2, H2O … (syngas)
- Syngas can be burned for electric power or converted to methane, liquid fuels, methanol, ammonia, or hydrogen
- Gasification is a leading approach for clean use of abundant coal
- Well-suited to pollutant and CO2 capture
- First U.S. patents in 1909 (Betts)
- Industrial-scale operations in Soviet Union.



LLNL has been active in UCG for decades

Past Tests (1970's and 1980's)

- 16 field tests at Hoe Creek, Centralia, Rocky Mountain
- Invented CRIP* process
- Extensive instrumentation and monitoring
- Cavity excavation
- UCG models and simulations



Silane igniter, Rocky Mountain

Current Activities

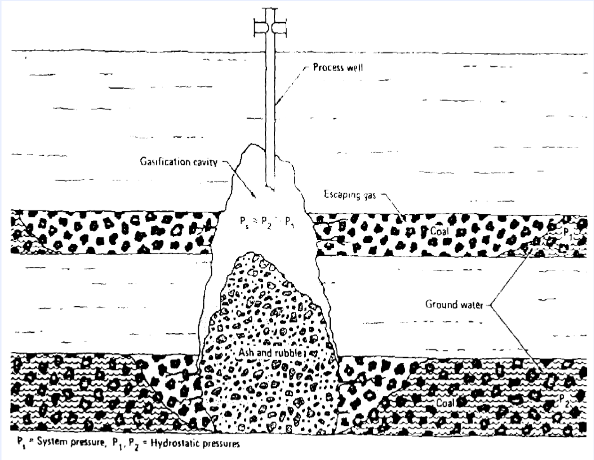
- Next generation UCG simulator
- Next generation UCG monitoring capabilities
- UCG program planning and site selection
- Site characterization and conceptual design
- Multi-disciplinary UCG team of 12 scientists and engineers

*Controlled Retractable Injection Point (CRIP)

Why monitor?

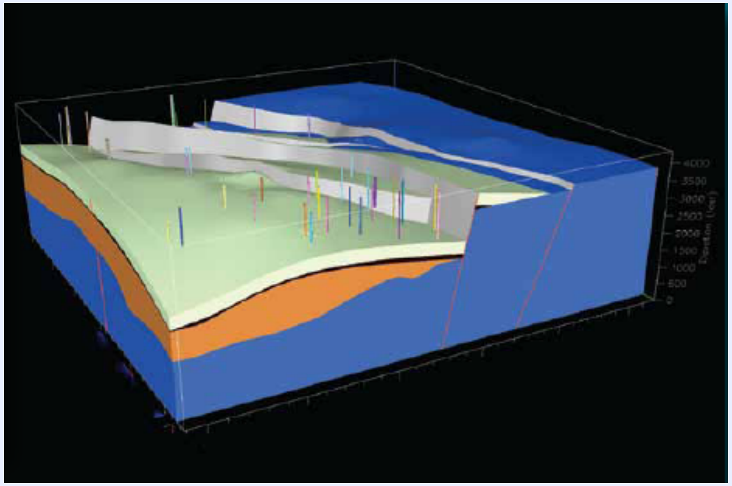
Operate more efficiently and responsibly

- Product gas quality
- Cost reduction
- Accelerate permitting
- Shield against liabilities
- Meet regulatory requirements



Inform control decisions

- Injection rate, composition, temperature, pressure
- Water pumping locations and rates
- Where to inject and produce
- Cavity size and growth; fractures
- When to stop



What to monitor?

- Process parameters
- Groundwater quality
- Hydrologic pressure field
- *Surface subsidence*
- *Cavity characteristics*
  - *Size, shape, temperature*
  - *Extent of fractures*

Surface subsidence

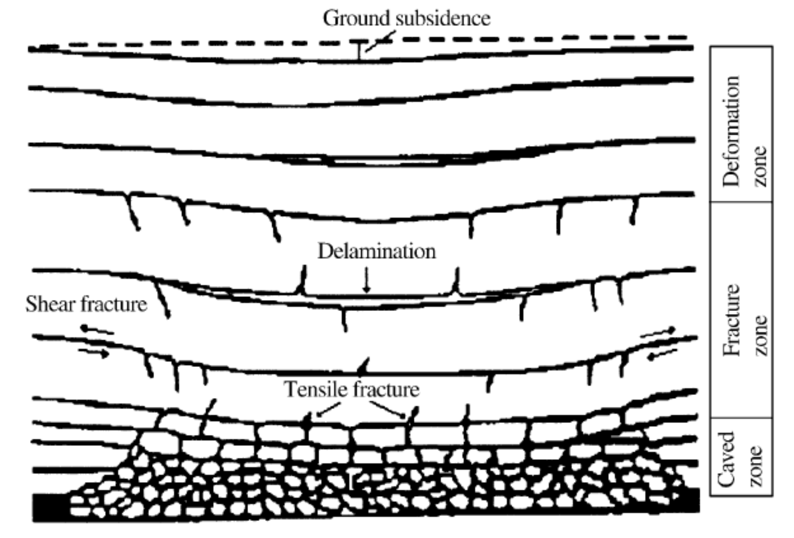
Managed with site selection

- Coal and rock properties
- Coal seam thickness, depth, and dip

Design and operations

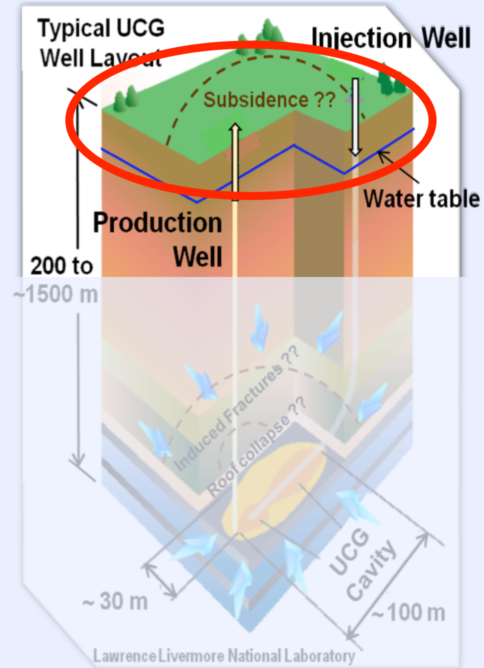
- Cavity/module widths
- Pillar widths
- Affects percentage of processed coal

Similar issues as in underground coal mining



Surface subsidence

- Avoid damage to infrastructure
- Infer potential roof collapse
- Liability

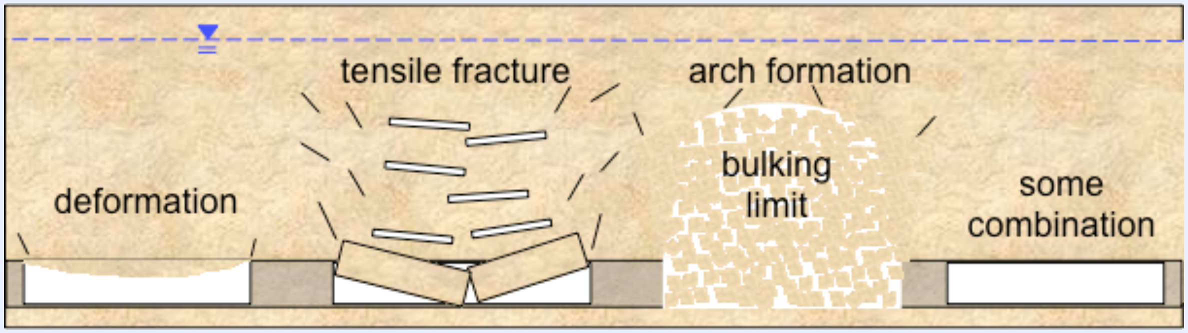


Bell et al. (1988)

Crown hole/chimney over coal mining operations.

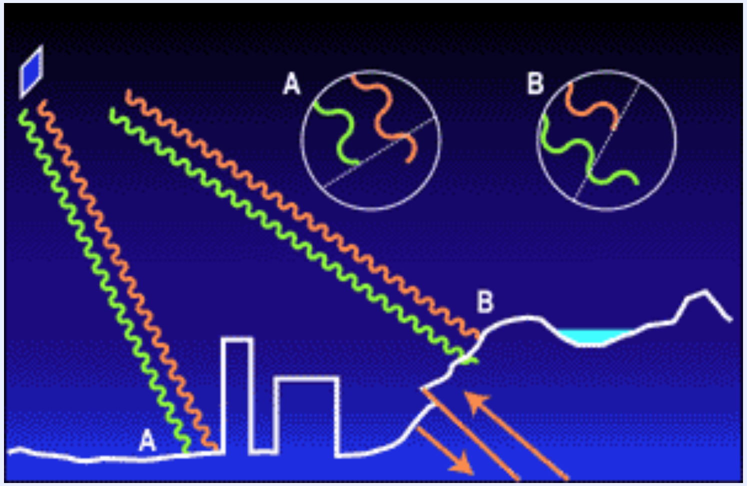
Several modes of failure are possible:

- Roof collapse
- Chimneying
- Plastic deformation



Types of subsidence monitoring

- Survey
- GPS
- LIDAR
- TDR
- *InSAR*
- *Tiltmeters*

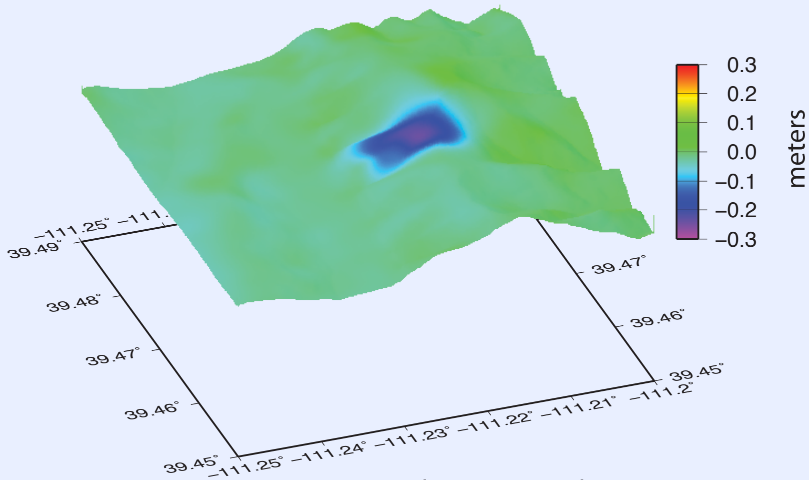


Tiltmeter

Subsidence monitoring by InSAR

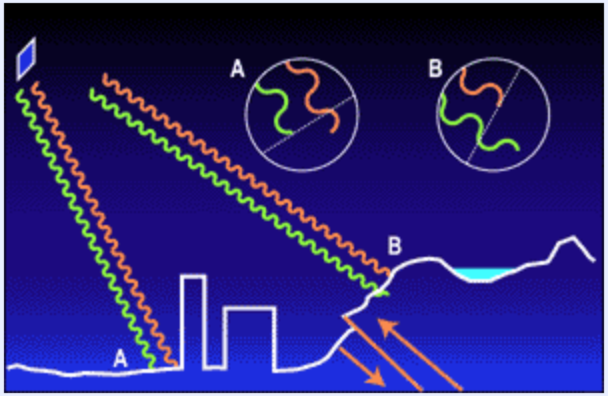
- **InSAR** - Interferometric synthetic aperture radar, a satellite based technology for deformation monitoring

Coal mining collapse observed with InSAR
Candall Canyon, Utah



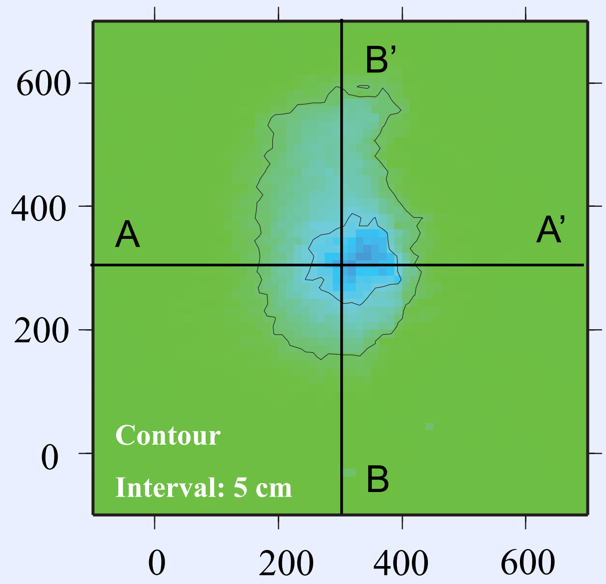
Draped on topography

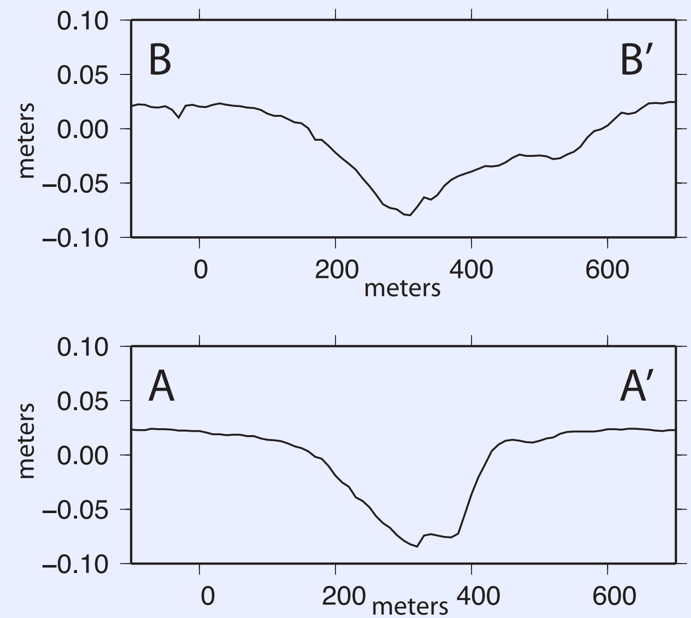
ALOS L-band PALSAR
6/2007 – 12/2009

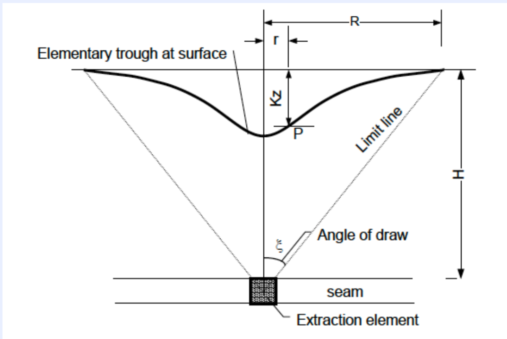


- Millimeter level of deformation accuracy
- Large-area coverage (~10,000 km^2/scene, 8m × 8m pixel)

UCG deformation observed with InSAR





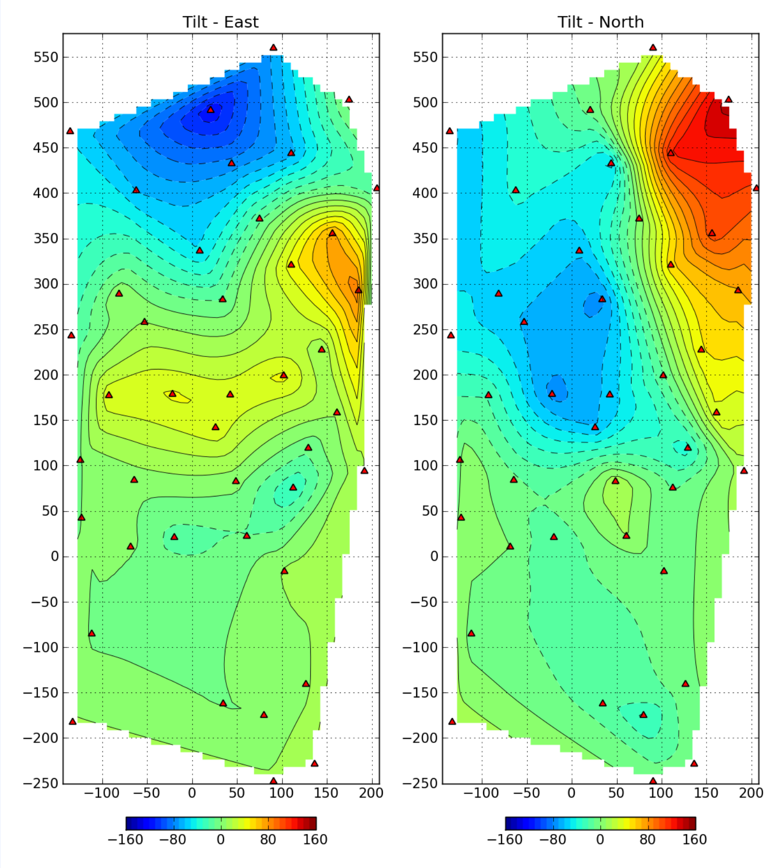


InSAR image showing surface deformation over an on-going UCG project

Tilt – real-time subsidence monitoring tool

- High data sampling rate
- High resolution
- Install near surface or in borehole
- Yields spatial derivative of deformation

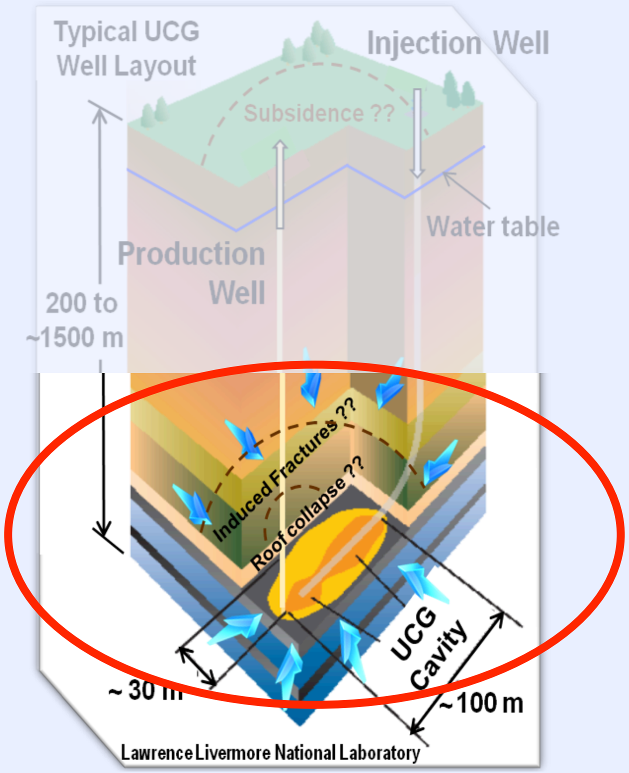
Tiltmeter



Tilt monitoring of enhance oil recovery (EOR)
LLNL, 2011

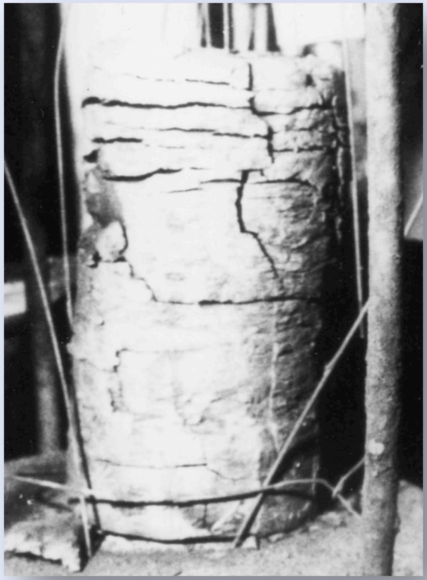
Cavity geometry and fracture detection

- Variety of methods possible
- Seismic reflection
- Passive microseismic
- In-seam seismic
- Electrical resistivity tomography



Passive microseismic monitoring

- Locate fracturing and spalling
  - Micro-seismic used in coal mines
  - Hydro-fracs and geothermal
- UCG signal
  - Low-amplitude continuous ‘noise’ with burst-like signals
  - Requires geophones within 50 m
  - Localized acoustic activity near burn front
  - Micro-seismic activity in overburden
  - Caused by both geomechanical and thermal effects
- Processing algorithms leverage extensive LLNL expertise in seismic monitoring



Overburden core from Hoe Creek UCG site after heating to 1000° C

(ORNL, 1977)

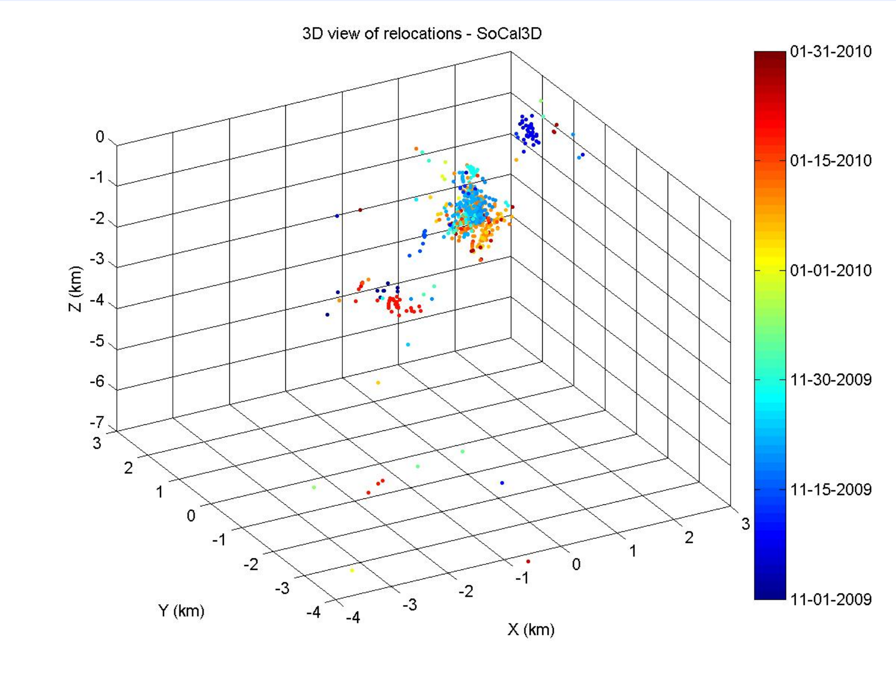
Microseismic monitoring development at LLNL

Improved detection

- Empirical matched filter detection
- 300% improvement over standard methods
- Robust to source differences

Improved location

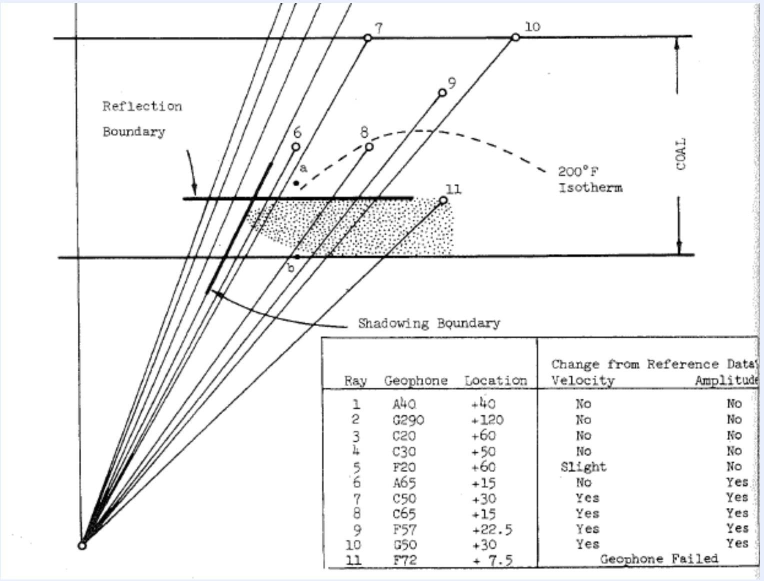
- Multi-event location algorithm
- Bayesian error estimation for realistic error



Wang et al, (GRC, 2011)

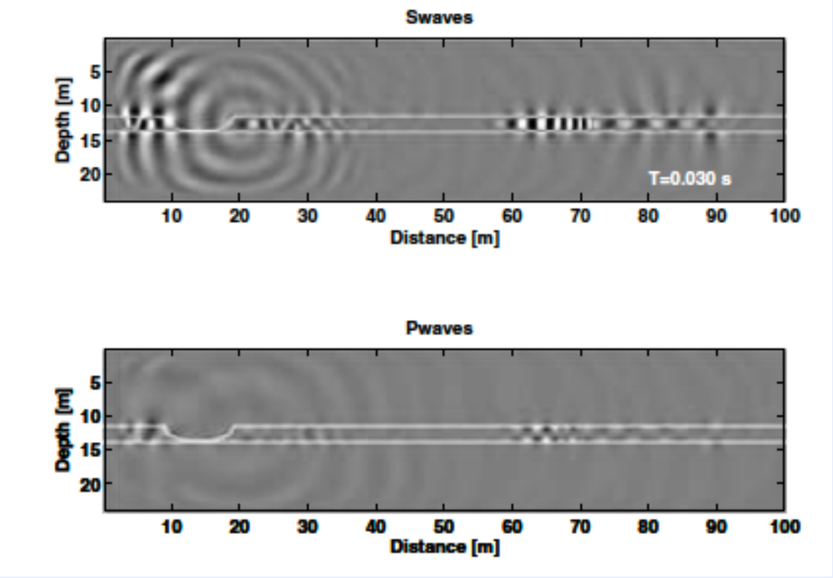
Seismic tomography and in-seam seismic

- Possible to delineate reaction region with tomography
  - Variations observed in amplitude and travel times
- In-seam seismic evaluates seam thickness and continuity
  - Changes in seismic velocity
  - Changes in scattering, attenuation, and waveforms



Ray	Geophone	Location	Change from Reference Data: Velocity	Amplitude
1	A40	+40	No	No
2	G290	+120	No	No
3	C20	+60	No	No
4	C30	+50	No	No
5	F20	+60	Slight	No
6	A65	+15	No	Yes
7	C50	+30	Yes	Yes
8	C65	+15	Yes	Yes
9	F57	+22.5	Yes	Yes
10	G50	+30	Yes	Yes
11	F72	+ 7.5	Geophone Failed	

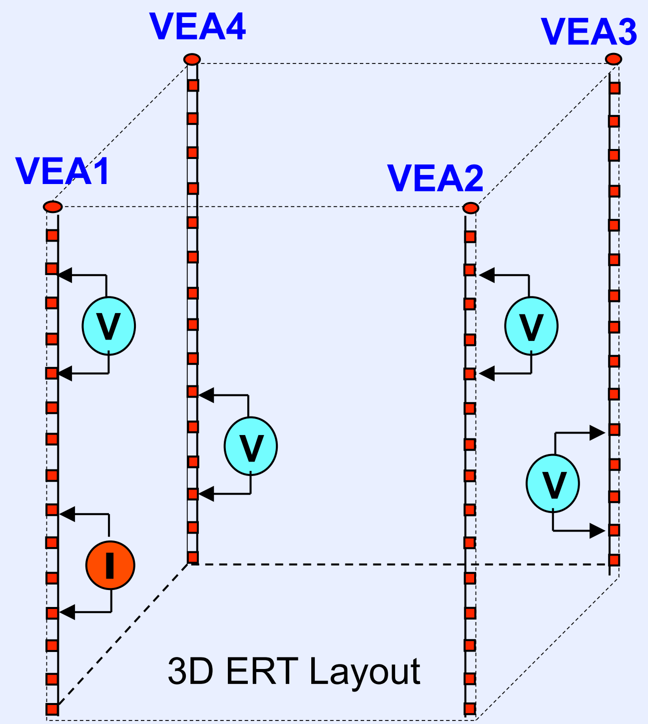
Beckham et al., 1979



Essen et al., 2007

Electrical Resistivity Tomography (ERT)

- Resistivity is a function of temperature, air/fluid saturation, salinity, and porosity
- Inexpensive sensors (metal stakes)
- ERT arrays can be collocated with thermocouple or groundwater monitoring wells
- Data collection and processing can be automated



UCG Monitoring Objectives by ERT

- Locate burn front
- Delineate cavity boundary
- Resolve temperature distribution

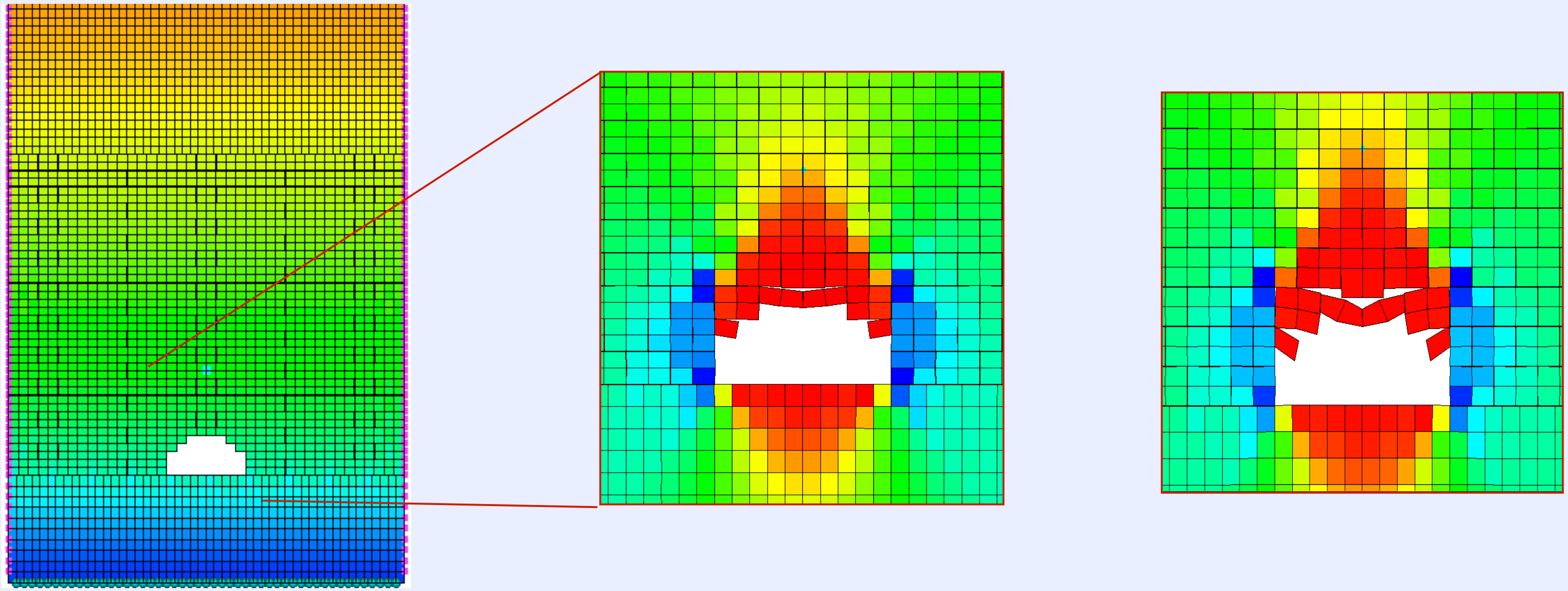
VEA – Vertical Electrode Array

I Transmitter injects current into the earth

V Receiver measures voltage

Linking monitoring and simulation : geomechanical modeling

- Infer cavity shape from geophysical data
- Combine observational data (e.g. geology, subsidence, seismic, ERT) to constrain models



Conclusions

- **Goals of UCG Monitoring**
  - Increase efficiency
  - Operate more responsibly

- **New monitoring methods being developed**
  - InSAR and tilt
  - Passive microseismic
  - Seismic tomography and in-seam
  - Electrical resistance tomography

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